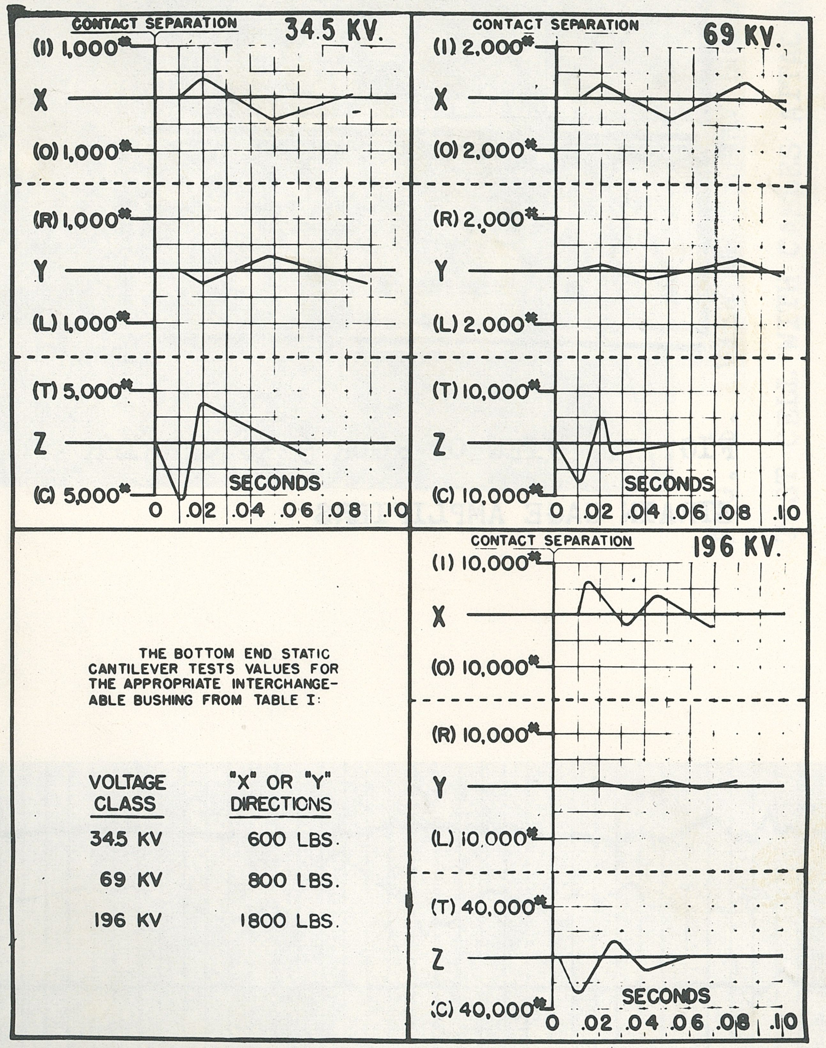

THE BOTTOM END STATIC CANTILEVER TESTS VALUES FOR THE APPROPRIATE INTERCHANGEABLE BUSHING FROM TABLE I:

VOLTAGE CLASS	"X" OR "Y" DIRECTIONS
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69 KV	800 LBS.
196 KV	1800 LBS.

FIG. 9. TYPICAL BUSHING LOADINGS UNDER RATED FAULT DUTY

Conference Paper

MECHANICAL LOADINGS ON CIRCUIT BREAKER BUSHINGS

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MECHANICAL LOADINGS ON CIRCUIT BREAKER BUSHINGS

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INTRODUCTION

The standardization of the electrical and dimensional characteristics of outdoor apparatus bushings for transformers and power circuit breakers was a landmark. It represented a "give-and-take" on the part of all apparatus and bushing manufacturers. For every rating, the standardization of dimensions resulted in a new bushing and the respective apparatus was modified to accommodate it. After several years of experience with these new bushings, there is general satisfaction: the bushing manufacturer because of the fewer bushing designs; the apparatus manufacturer because interchangeability permits him to use bushings from several suppliers without apparatus changes; and the user because fewer spare bushings need to be stocked.

Yet, one question was not fully answered by this initial step. Would the apparatus perform up to its rating when equipped with bushings other than the furnished design? This question was primarily concerned with the mechanical strength of the bushing structure. The electrical characteristics, that is, insulation strength and thermal capacity, were a part of the dimensional standardization.

By definition[1]:

> "A bushing is an insulating structure including a central conductor, or providing a central passage for a conductor, with provision for mounting on a barrier, conducting or otherwise, for the purpose of insulating the conductor from the barrier and conducting current from one side of the barrier to the other."

This definition can be met with a mechanical design that remains liquid-tight over the normal operating temperature range, endures normal handling and transportation without misalignment or liquid leakage, and passes short-circuit current without damage to the conductor or insulation. Meeting these requirements would in general produce a satisfactory transformer bushing.

Bushings for circuit breakers are subjected to much higher mechanical loadings. In addition to the requirements outlined above, they serve to support the stationary interrupter contact assemblies which not only have to carry short-circuit current but also have to interrupt it.

The interrupter assembly, which is an enclosure around contacts, is designed to contain the pressures developed by drawing an arc in oil. Efficient interruption of the arc requires an instantaneous buildup of this pressure, usually in less than one loop of short circuit current, so that conditions are favorable for interruption at the first current zero after the contacts part. This generation and dissipation of energy is reflected onto the supporting bushing structure. All other loadings are minor by comparison. During this period of several cycles, the bushing must maintain its oil tightness and alignment.

This difficult requirement has been appreciated by circuit breaker and bushing manufacturers for many years. Proof-testing of bushings has therefore become a necessary part of breaker interrupting tests. In other words, a bushing design was only considered adequate when it successfully withstood tests in the breaker with which it was to be used.

Such a procedure, if continued, would nullify some of the advantages of the present bushing standardization. Breaker manufacturers could not use bushings interchangeably and would need to test every design independently. Bushing manufacturers could not recommend their bushings for circuit breakers unless they had knowledge of a prior proof test. Users of bushings would have interchangeability under emergency conditions, but to be within the breaker warranties, would have to make a later replacement with the original type of bushing.

This situation has been the subject of numerous discussions in the appropriate industry committees and a proposal is now being reviewed that would establish the additional standardization of the mechanical requirements for apparatus bushings. It is appreciated that this proposal is only in the discussion stage, but it is desirable to refer to it because it bears directly on the subject of this paper.

This proposal reads in part:

Mechanical Requirements

(a) Apparatus bushing shall withstand without leakage an internal pressure test of two (2) times the maximum pressure that occurs during the thermal test.

(b) Bushings shall not leak or exceed permissible permanent deformation when subjected to cantilever loads listed in Table I.

(c) In all instances where the bushing is interchangeable between circuit breakers and transformers, the bushings shall meet the mechanical requirements of both circuit breakers and transformers.

Cantilever Test Values for Outside Apparatus Bushings

These cantilever test values are based on bushing flanges being rigidly mounted with load applied normal to the axis of the bushing and at the midpoint of the thread on threaded terminals and at the lower terminal plate on bushings so equipped.

The loads are those static loads which will be sustained by the respective bushings for a period of one minute without causing a permanent deflection of greater than 0.032 inch on the bottom end after the load has been removed or resulting in oil leakage at any time either during or within ten minutes after the application of the load. For top end values, only the oil leakage requirement is pertinent.

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Conditions for the test would be:

Bushing internal pressure 10 psi gauge.

Temperature 25°C approximately.

Permanent deflection measured at approximately one minute after removal of transverse force.

A typical load-deflection curve on a 196-kv class bushing which was made in accordance with the above procedure is shown by Fig. 1. After the removal of all loading, this bushing returned to its original position and had no permanent deflection.

Table I, which has been copied from the proposal, includes a footnote that summarizes the majority opinion relative to cantilever test values that are listed.

> There are no cantilever values yet developed which are considered satisfactory, nor is there a clear definition of the factors involved. It is recognized that the forces involved are oscillatory in nature and consist both in magnetic reaction due to current and pressure reaction from interrupters. Work is being done to develop appropriate values and test methods of applying an oscillatory cantilever load to bushings for application in circuit breakers. In the interim these static cantilever load tests should be considered only as a first approximation.

TEST PROGRAM

This was the situation which existed when plans were being formulated to conduct a series of high-power laboratory interrupting tests on a number of outdoor oil circuit breakers. Discussions of this mutual bushing problem between the two companies of which the authors are members developed into a joint program to measure the transient loadings to which bushings are subjected while circuit breakers are interrupting short circuits.

The oil circuit breakers to be tested were of the conventional dead-tank construction equipped with modern oil-blast interrupters and pneumatic operating mechanisms for high-speed reclosing. Three ratings of breakers were tested: 34.5 kv, 69 kv and 230 kv. The bushings for each rating conformed with the latest ASA standards. The 34.5-kv and 69-kv bushings were rated at 1200 amperes, and the 196-kv bushings were rated at 1600 amperes. The breakers were tested under various short-circuit duty cycles and up to their short-circuit ratings which are 1,500 mva for the 34.5-kv breaker, 2,500 mva for the 69-kv breaker, and 15,000 mva for the 230-kv breaker.

Since this paper is concerned primarily with the measuring of the loadings of the bushings under test, further reference will not be made to the breaker interrupting performance. This has been the subject of a previous paper[2].

BUSHING INSTRUMENTATION

The problem of measuring the loadings on the breaker bushings was complicated by many factors. Any method used must not be affected by the high magnetic fields. The deflection of the lower bushing terminal could not be measured conveniently because it was at high voltage. Measuring the sequence and magnitude of the forces in different directions by mechanical means would be very difficult.

The use of electric strain gages had been previously investigated. The problem of voltage pickup generated in the lead wires had not been satisfactorily solved with DC voltage strain-gage bridges. A 2-kc carrier-type bridge indicated so much improvement that it was felt that a higher frequency carrier might be successful. It was found that a commercially available 5-kc carrier-type strain gage amplifier substantially eliminated pickup although it was necessary to closely twist the lead wires.

It was decided to instrument the bushing ground sleeve to measure the forces outlined in Fig. 2. It was considered that the bushings might, as a result of interrupter design or support vibration, be called upon to withstand other forces, such as a force couple, that would not be accurately defined by the components shown. These other forces, however, would be of small magnitude. The measurement of torsional forces was not successful due to "cross talk" with other channels. These effects can be overcome, but the torsional load data obtained on this series of tests were not considered sufficiently accurate to discuss further here.

The strain gage arrangement and connections to measure the forces are indicated in Fig. 3. The gages were attached in a band about the middle of the ground sleeve. The X, Y and Z channel gages were arranged in four vertical rows accurately spaced at 90° and were oriented with respect to the power factor tap as shown. A plane defined by the axes of the two breaker bushings passed through the centers of the X and Z gages.

Because of their extensive use in strain analysis, many different types of strain gages and cements were available. It was found that 1/4-inch foil-type, 120-ohm gages were convenient to apply. The contact cement activator accelerated the curing time so that the gages could be quickly attached. Short flexible leads were soldered to the gages and then closely twisted. Epoxy resin was applied over the gages and the gage end of the twisted leads to seal against moisture and provide mechanical protection. The insulation between all strain gages and the ground sleeve was tested to 2000 volts DC because the test cell ground differed from the control room ground by several hundred volts during tests.

Shielding against the effects of high voltage fields was accomplished as outlined in Fig. 4. The short leads connecting the strain gages to the shielded jacketed cables were first secured in place by plastic tape as shown in Fig. 5. Varnished cambric tape was then applied followed by copper mesh braid. The shields of all the lead cables were connected to this braid. Secondary shielding was provided by an aluminum foil which was attached to the bushing ground sleeve. Painted cotton tape covering the foil gave mechanical protection.

The commercially available strain gage connection cable had four active conductors with foil shielding and a plastic jacket. Each cable was brought into the current transformer connection housing with an AN bulkhead connector. The shells of all cable connectors were earthed to the breaker frame. Cables, approximately 125-feet long, were used between the bulkhead connectors and the strain gage carrier amplifiers located in the control building. Fig. 6 shows the 230-kv test breaker equipped with cables.

The amplifiers, Fig. 7, were equipped with resistors that permitted calibration before the bushings were installed in the breakers. These resistors could be connected in parallel with one leg of the bridge to produce a known unbalance. This same unbalance could be duplicated by a measurable static load applied at the lower bushing terminal. The outputs of the amplifiers were recorded on magnetic oscillographs.

TEST RESULTS

Oscillographic records were taken of the strain gage indications under many different duties for each of the breakers under test. Fig. 8 is typical of the strain gage records. It was made on a 196-kv class bushing during the interruption of 42,500 amperes.

As experience was gained, the records improved and indicated fairly consistent characteristics for a given bushing and interrupter combination. The curves of bushing loadings shown in Fig. 9 represent a simplified composite of several records that were taken at the rated interrupting duty of each of the breakers. These are therefore typical of the loadings that a bushing sees under rated fault duty.

CONCLUSIONS

The following conclusions are only a few of the observations that can be made from an initial study of the test data:

1. The measurement of transient loadings on circuit breaker bushings during short circuit current interruptions has been made successfully. This was done with strain gages attached to bushing ground sleeves, by the use of high frequency carrier type amplifiers, and by proper shielding.
2. The relationship between the actual transient loadings and the proposed static test load requirements is not entirely clear. It is hoped that other breaker manufacturers will include bushing loading investigations in their breaker testing programs. It is evident that the final answer will lie in appraising the performance of a number of different bushing and interrupter design combinations.
3. Some observations of the data are of interest:
   (a) The flow of short-circuit current before the contacts open has little loading effect on a bushing.
   (b) Transient loading on a bushing begins with the arcing and continues for several cycles after interruption.
   (c) Transient loading on a bushing is a resultant of several forces. Initially, a compression force is applied to the lower end. This is followed immediately by several cantilever forces acting from different directions. The bushing actually experiences a dynamic cantilever load that is at all times equal to the vectorial sum of X and Y.

   (d) High cantilever forces often occurred when the bushing was also experiencing a large tension load.

REFERENCES

1. American Standard for Apparatus Bushings and Test Code for Apparatus Bushings, AIEE Standard No. 21, (July 1943), (ASA C76.1).

2. High Power Laboratory Tests on High Capacity High Voltage Oil Circuit Breakers, Noel E. Reed and Earl B. Rietz, AIEE Transaction Paper No. 59-846.

TABLE I

1	2	3	4
INSULATION CLASS KV	RATED CONTINUOUS CURRENT AMPERES	CANTILEVER TEST VALUE TOP	BOTTOM
23	400 (1)	150	300
	1200 (1)	150	300
	1200 (3)	200	600
	(3000) (1)	150	300
	(3000) (2)	300	800
34.5	400 (1)	150	300
	1200 (1)	150	300
	1200 (3)	200	600
	(2000) (1)	150	300
	(2000) (2)	300	800
46	400 (1)	150	300
	1200 (1)	150	300
	1200 (3)	200	600
69	400 (1)	150	300
	1200 (1)	150	300
	1200 (3)	300	800
	(2000) (1)	150	300
	(2000) (2)	600	1200
92	800 (1)	150	300
115	800 (1)	150	300
	1200 (3)	600	1200
	1600 (3)	700	1400
	(2000) (2)	800	1800
138	800 (1)	150	300
	1200 (3)	600	1200
	1600 (3)	700	1400
	(2000) (2)	800	2200
161	800 (1)	150	300
	1600 (3)	800	1800
180	800 (1)	150	300
196	800 (1)	150	300
	1600 (3)	800	1800
230	(800) (1)	150	300
	(1600) (3)	800	1800
287.5	(800) (1)	150	300
	(1600) (3)	800	2200

Brackets ( ) indicate ratings being developed.
(1) Transformer Bushings.
(2) Circuit Breaker Bushings.
(3) Interchangeable Bushings.

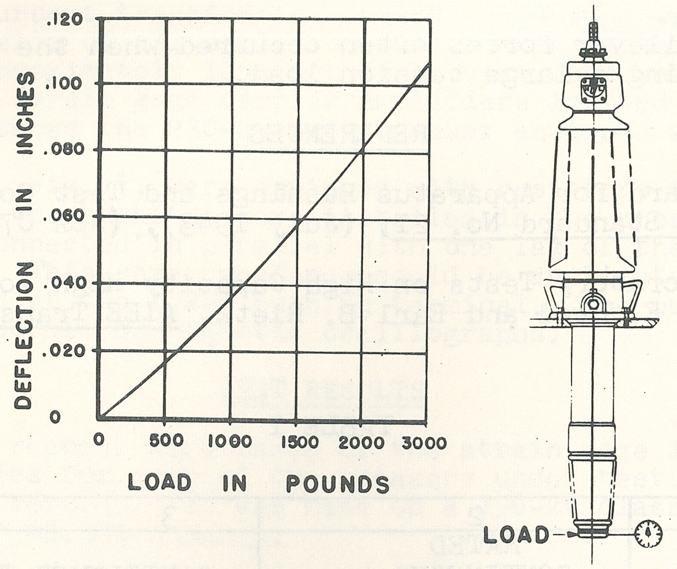
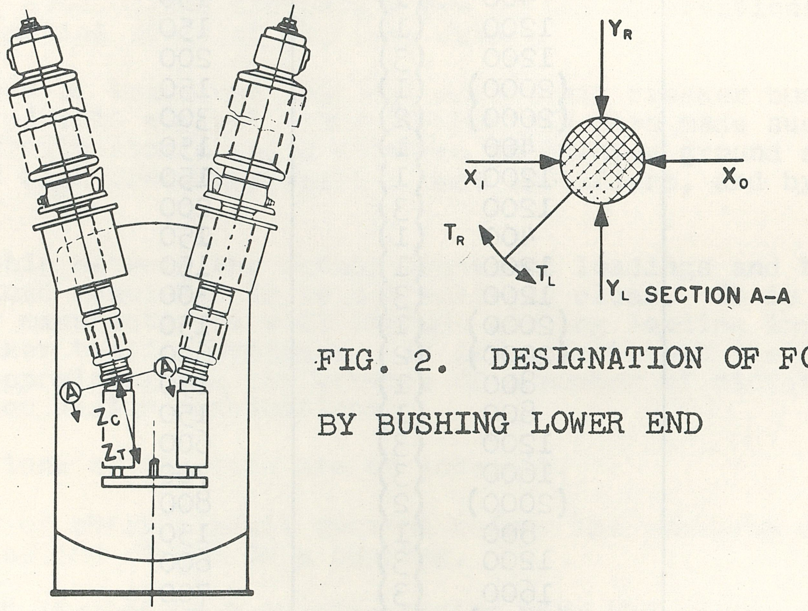


FIG. 1. TYPICAL LOAD-DEFLECTION CURVE FOR 196-KV 1600 AMPERE BUSHING



Y_R
X_I
X_O
T_R
T_L
Y_L
SECTION A-A
A
A
Z_C
Z_T

FIG. 2. DESIGNATION OF FORCES SEEN BY BUSHING LOWER END

X_I - Forces tending to move the lower terminal (in) toward the other bushing.

X_O - Forces tending to move the lower terminal (out) away from the other bushing.

Y_R - Forces tending to move the lower terminal to the right.

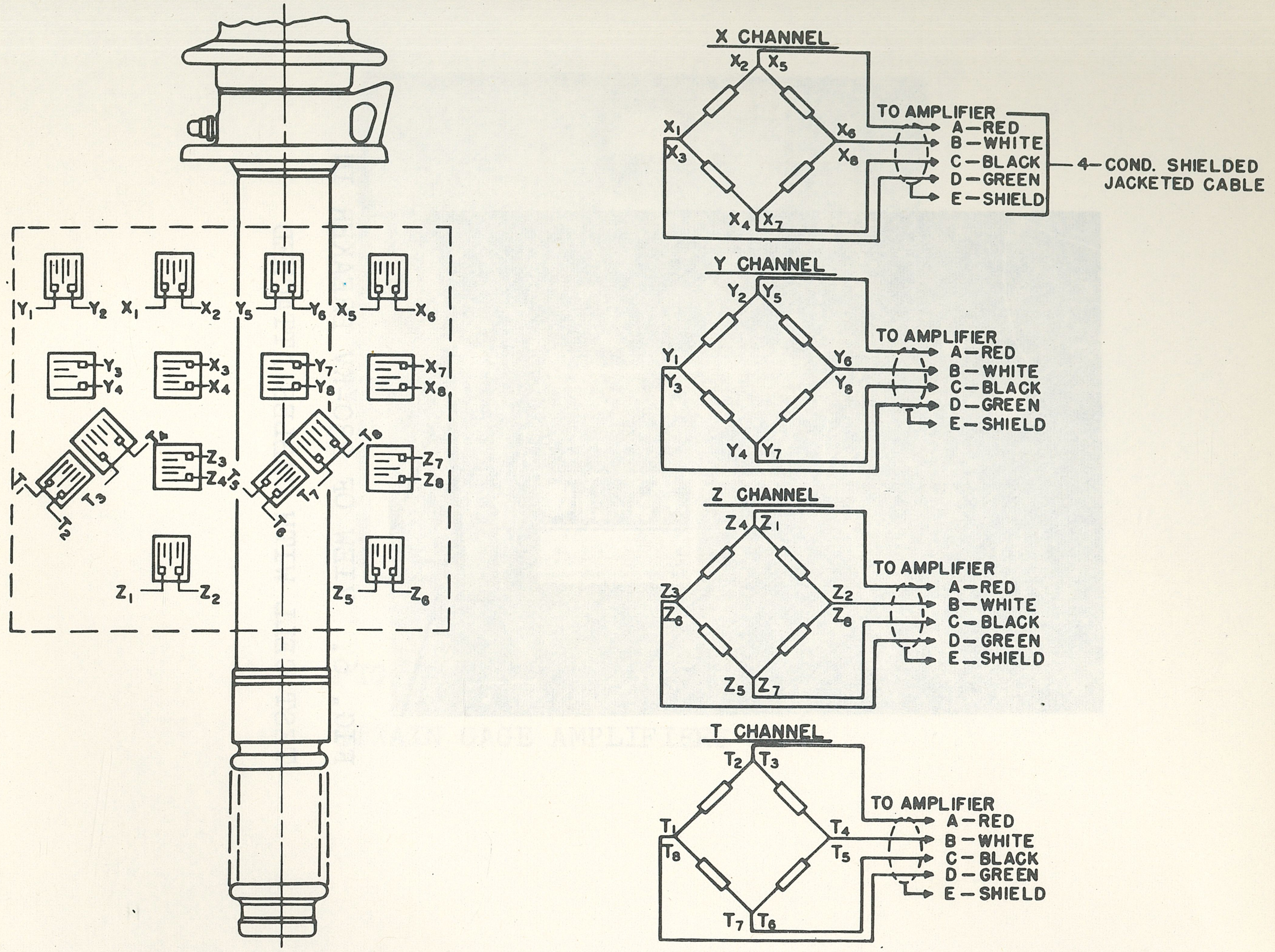
Y_L - Forces tending to move the lower terminal to the left.

Z_T - Forces tending to exert tension on the lower terminal.

Z_C - Forces tending to exert compression on the lower terminal.

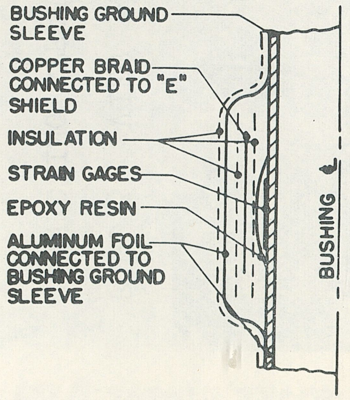
T_L - Torsion forces on lower terminal that are counterclockwise.

T_R - Torsion forces on lower terminal that are clockwise.



Y_1
Y_2
X_1
X_2
Y_5
Y_6
X_5
X_6
Y_3
Y_4
X_3
X_4
Y_7
Y_8
X_7
X_8
T_1
T_2
T_3
T_4
Z_3
Z_4
T_5
T_6
T_7
T_8
Z_7
Z_8
Z_1
Z_2
Z_5
Z_6
X CHANNEL
Y CHANNEL
Z CHANNEL
T CHANNEL
TO AMPLIFIER
A—RED
B—WHITE
C—BLACK
D—GREEN
E—SHIELD
4-COND. SHIELDED JACKETED CABLE

FIG. 3. LOCATION OF STRAIN GAGES ON BUSHING GROUND SLEEVE AND SCHEMATIC DIAGRAM OF STRAIN GAGE BRIDGE CONNECTIONS



BUSHING GROUND SLEEVE
COPPER BRAID CONNECTED TO "E" SHIELD
INSULATION
STRAIN GAGES
EPOXY RESIN
ALUMINUM FOIL CONNECTED TO BUSHING GROUND SLEEVE
BUSHING ℄

FIG. 4. DIAGRAM OF ELECTROSTATIC SHIELDING OF STRAIN GAGES ON BUSHING GROUND SLEEVE

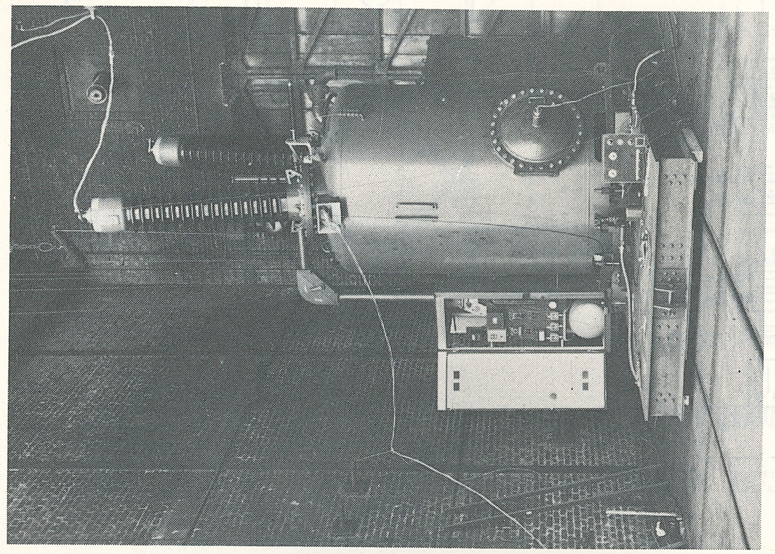


FIG. 6. VIEW OF 230-KV BREAKER IN TEST CELL WITH CABLES ATTACHED

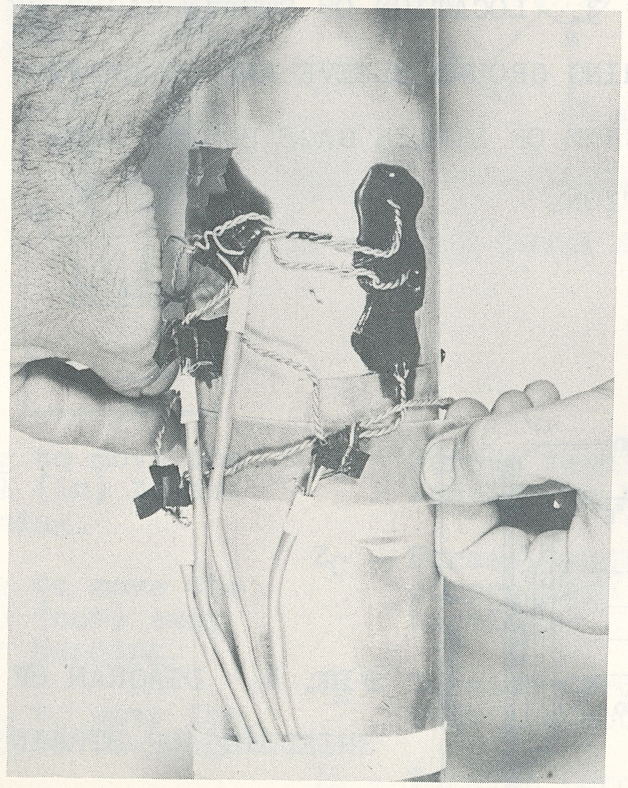


FIG. 5. VIEW SHOWING TWISTED LEADS CONNECTING STRAIN GAGES TO CABLES

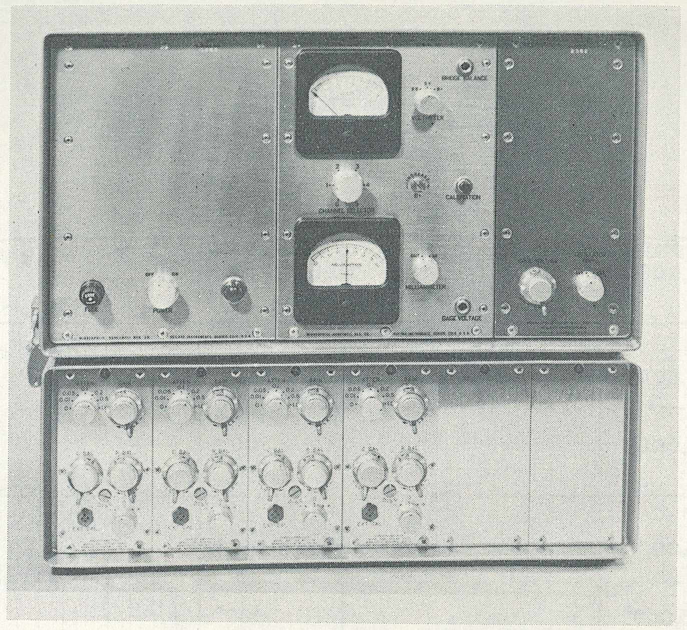


FIG. 7. VIEW OF FOUR 5 KC CARRIER STRAIN GAGE AMPLIFIERS

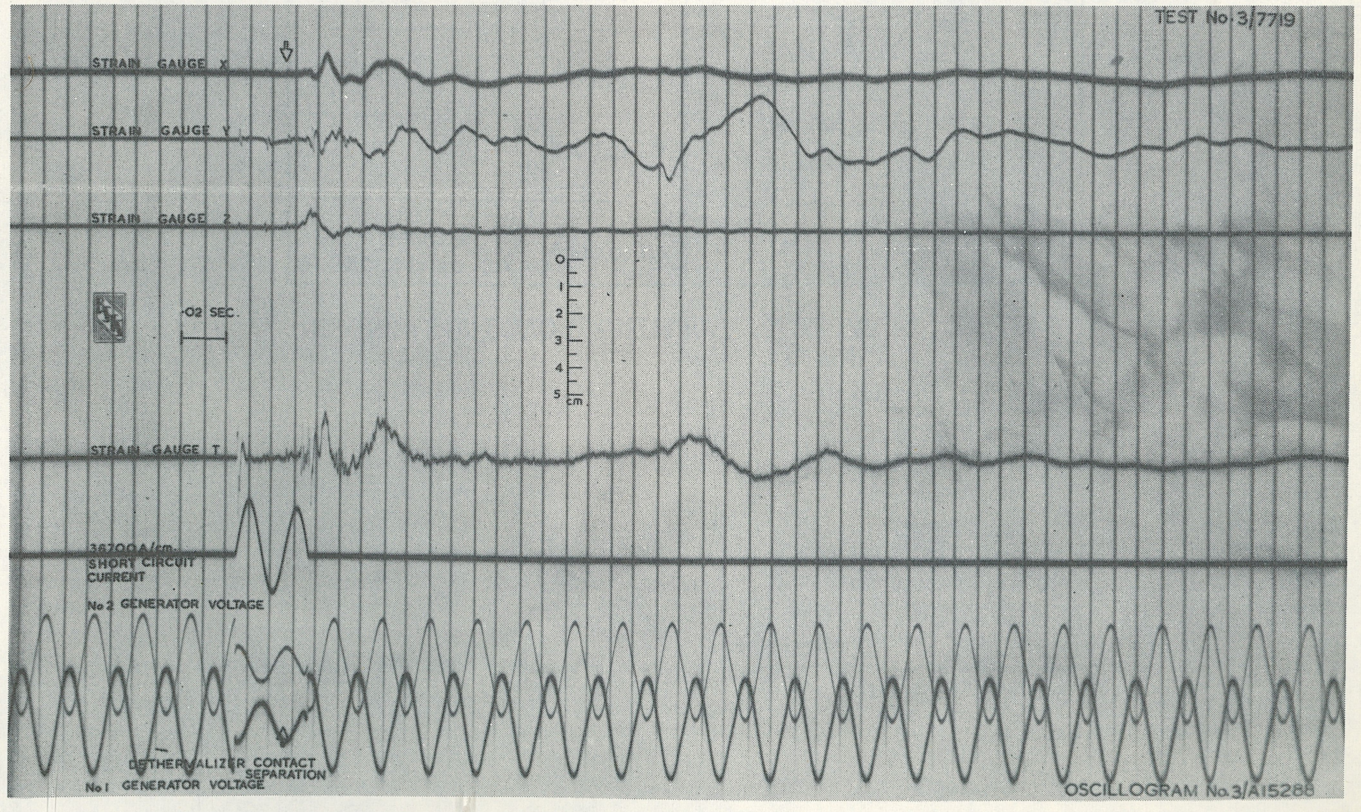
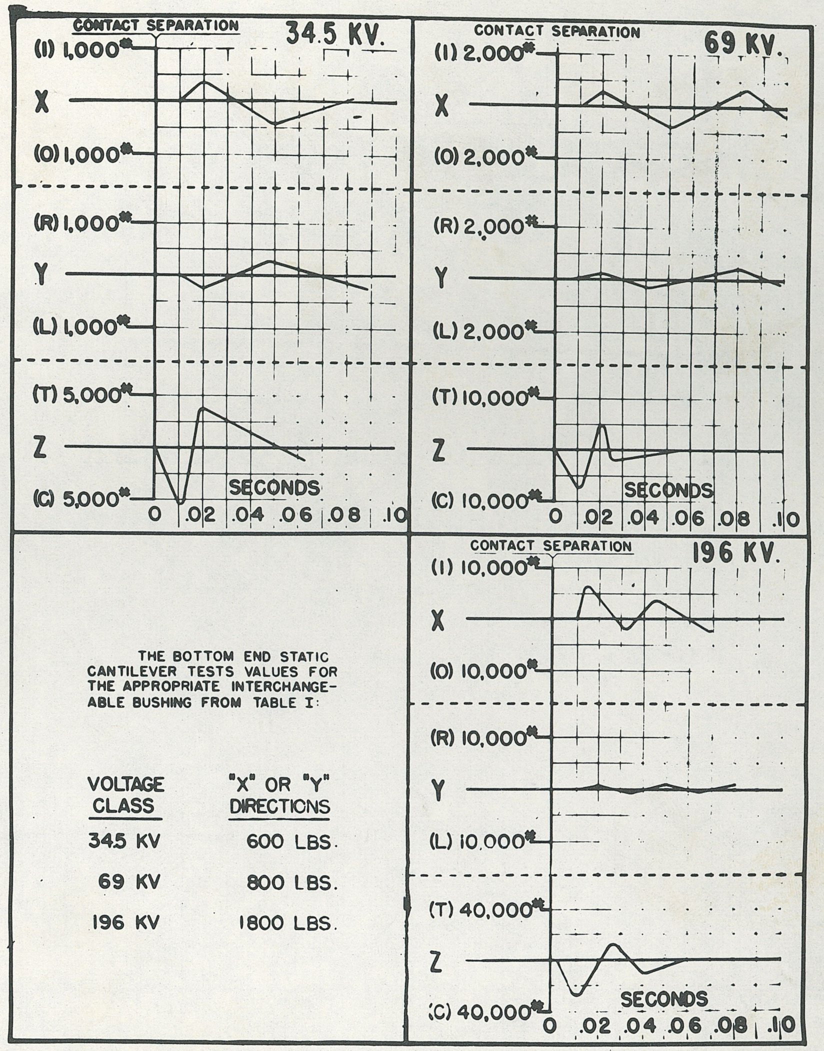


FIG. 8. OSCILLOGRAPHIC RECORD OF STRAIN GAGE READINGS OF THE 196-KV BUSHING DURING INTERRUPTION OF 42,500 AMPERES



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